# Synthetic Deformed Bars and Retaining Walls



Continuity

This application claims the benefit of U.S. provisional patent application Number 60/261,486, Doc. No. 7291 filed January 13, 2001, and is a continuation-in-part of PCT patent application number PCT/US01/05733, filed February 22, 2001, which designates the United States of America and claims the benefit of U.S. provisional patent application Number 60/184,049, filed February 22, 2000. These patent applications are incorporated by reference herein in their entirety.

## Background of the Invention

Various methods have been used to construct precast walls for retaining earth, soil, sand or other fill (generally referred to as soil). A typical precast wall system is disclosed in U.S. Patent No. 4,914,876, assigned to the Keystone Retaining Wall System, Inc. by Paul J. Forsberg. The Keystone Patent illustrates a typical modular block wall system wherein the wall face is comprised of concrete masonry units connected to geosynthetic wall reinforcement layers. The geosynthetic tensile inclusion members for this type of retaining wall structure are typically referred to as "geogrids."

A disadvantage of such a system is that a considerable amount of hand labor is required to install the numerous small block facing units of the block wall system. This requirement limits the amount of wall structure that can be completed in any work shift. In addition, if the wall is placed on weak foundation soils, a manifestation of wall settlement is cracking or more significant crushing or crumbling of the facing units. If wall settlement is excessive, the geogrid material can be sheared where it connects to the concrete masonry unit horizontal joints, which can result in wall failure.

Numerous other types of concrete block mechanically stabilized earth wall systems are available. These systems, like the Keystone System previously described, mandate precise grading and compacting of the wall backfill to correspond to increments of the vertical height of the block

facing units so that the tensile inclusion materials used to mechanically reinforce the retained wall backfill material can be placed at the horizontal joint elevations of the concrete masonry units. Although the material costs for these types of wall systems are low, the high labor costs for the various stages of wall construction can result in installed price of walls that are substantially higher than the material costs.

Other mechanically stabilized earth walls include walls that use precast concrete panels for the wall facing elements, such as walls disclosed in U.S. Patent No. 4,961,673, issued to Pagano et al.; and U.S. Patent Nos. 3,421,326; 3,686,873; and 4,116,010 to Vidal. Such wall systems require the use of metal reinforcing strips or steel grids as soil inclusion members in the wall backfill. Those members are connected to the precast wall panels to hold the panels in place and to provide stability for the wall backfill.

A disadvantage of walls that use metal soil reinforcement is that the metal soil tensile inclusion members are subject to corrosion, because the metal is in direct contact with the wall backfill. Numerous catastrophic failures have resulted from the effects of unchecked corrosion on the metal tensile inclusion members for these wall systems. Although soil inclusion members (e.g., metal strips or steel grids) can be galvanized to resist the corrosive effects of the oxidation process, this technique is not effective for all soil types due to the diverse mineral content present in some soils. Other methods, such as epoxy coating of the metal soil inclusion members, have been used to further resist the deleterious effects of potential chemical reactions of the soil minerals with the soil inclusion members. A disadvantage of the epoxy coating, however, is that the coating is easily scratched during the construction, which results in the exposure of the metal soil reinforcement to the corrosive effects of minerals present in the backfill. Also, epoxy coatings increase the costs of these systems.

Another factor that increases the likelihood of premature failure of MSE walls that use steel soil reinforcement is the reduced sliding friction of the soil reinforcing material at the onset of the effects of corrosion. Because corrosion commences from the outside surface of the reinforcing material, the corrosive residue becomes the material that is in contact with the soil following the commencement of corrosion. The interface of the corrosion layer with the steel soil tensile reinforcement member is therefore the weak link. The remaining competent steel material may move with respect to the corrosion layer. Movement between the soil fill and the soil reinforcement may also occur. The ultimate result of this relative movement could be premature wall failure.

Typical wall facing units for existing MSE systems in current use may range in size from 8′ x 16′ for block systems to 25 to 50 sq. ft. for precast panel wall systems. The concrete masonry block systems, due to the high unit weight and relatively small size of each block, do not require bracing or interlocking to hold the face units in a vertical position as the wall backfill is placed. Since the blocks are heavy (exceeding 100 pounds for some applications), the placement of the blocks is physically demanding, which adds to the placement cost of the facing units. MSE wall systems that use panels for wall facing are large in size compared to the block facing units, and the panels (typically between 25 to 80 sq. ft. in area) are held in place during backfilling operations by interlocking with previously placed or adjacent panels. For some systems, the facing units are "wedged" or leaned by other methods so that the effect of the interaction of the backfill pressure and the metal soil reinforcement will, in theory, force the panels into a plumb or vertical position. Panel placement for these systems requires experienced workers to erect the units so that the resultant structure will be vertical and not leaning either in or out of a vertical plane.

Full height panels have been used on MSE walls where the MSE layers are connected to the wall face. Temporary erection braces are required for

these systems to hold the panels in place because the backfill is placed behind the wall. This requires additional working right-of-way in front of the wall and restricts site access. Because the soil reinforcement material (e.g., geosynthetic or metal) is not designed for concentrated high loads at the connections of the soil reinforcement material, the panel connections should, in theory, have quantifiable uniform loads. This condition is extremely difficult, if not impossible, to achieve in the field. This difficulty is one of the primary reasons why few full height MSE panel walls have been built with precast face units. An indeterminacy situation exists for the load determination at the numerous connections of the soil reinforcement material to the panels for these types of walls since, typically, the number of soil reinforcement connections to the wall facing exceeds the number of equations available to solve for the individual connection loads.

There is a portion of retained soil loading on the wall face in full height and all MSE panel systems currently in use. Vertical settlement (relative motion) between the tensile inclusion soil reinforcement layers and the panel face can induce excessive shear loads on the soil reinforcement material at the connection point to the panel. Typically there is no adequate provision to allow for this vertical movement without inducing shear forces on the tensile inclusion material at the connection to the wall face for the systems currently in use. Many panel connection devices have been installed and utilized for these various systems currently in use wherein the wall face can, in theory, move with respect to the soil reinforcement material. Panel connections, such as vertical bolts supported by clevises cast into the panels that are connected to the metal trip soil reinforcement, have been used to allow for vertical movement. The high horizontal earth loading on the individual connections results in large friction loads at the bolts and, as a result, the relative motion desired at the connections has not typically been achieved. This condition is exasperated because the currently available MSE wall systems do not utilize soil reinforcement that has significant bending moment resistance or shear strength, even though the soil reinforcement may

have high tensile capacity. Vertical settlement of the whole MSE wall mass, wherein the panels move with the MSE structure is, for some sites a valid assumption because the forces supporting the vertical wall and backfill loads are uniform. Unfortunately, for certain wall sites, the retaining structure may rest on material that does not have uniform bearing capacity over the reach of the wall. For these sites, if there is compressible material under some portions of the MSE mass, the structure will not settle uniformly. This can result in differential settlement between the wall elements and the wall mass, which can lead to structural failures of varying degrees.

Another broad range of MSE wall types that have been used extensively for permanent and temporary retaining wall applications are wrapped face, or confined fill layers, that form a geotextile MSE wall. These walls are comprised of an assembly of vertically stacked layers of wall backfill confined by closed face sheets of geotextile that are typically placed in horizontal planes within the wall backfill as the backfill is placed and compacted. For temporary walls, the face of these walls is the exposed geotextile material. The geotextile material that retains the fill at the face of each layer is wrapped back into the fill behind the face of the wall. The wrapped back geotextile is imbedded into the backfill material behind the face of the wall for each compaction lift of fill that is placed. One of the difficulties associated with the construction of these types of earth retention structures is that the wrapped back face portion of each backfill layer requires that an external forming system be installed in front of the face of the wall to hold the geotextile face at the proper alignment until the wrap back portion of the geotextile layer is sufficiently imbedded in the backfill adjacent to the wall face. The associated fill pressure prevents the wrap back geotextile from being displaced horizontally. The cost of labor associated with the placement and operation of the external forming system adds to the cost of these types of walls.

Whether the geotextile wall is a temporary or permanent structure, a face forming grid is required during wall construction so that the

resultant overall wall face will conform to the wall alignment limits. For permanent geotextile walls, it is necessary to cover the exposed wall face so that the geotextile will be protected from the deleterious effects of prolonged exposure to ultraviolet radiation. Although the geotextile material is corrosion-resistant with respect to the soils and minerals that the material may come into contact with due to the embedment in the wall backfill, the long-term effects of exposure to the sun can result in the ultimate deterioration of the wall face. Various facing materials that have been used to cover the face of geotextile walls . The facing materials include, for example, sprayed concrete faces, precast or cast-in-place concrete panels. The use of a sprayed concrete faces requires that attachment fasteners, such as lengths of wire or pieces of rebar, be installed in the wall and protrude from the face of the wall to form a connection between the sprayed on concrete and the exposed geotextile surface. The disadvantage of walls with this type of face is that the wall surface is typically not uniform and not aesthetically pleasing. Additionally, if the walls experience any significant long-term settlement, cracking and spalling of the sprayed concrete face can occur.

Precast facing elements have also been attached to wrapped face geotextile walls by the use of long bolts or thread bar anchors that are screwed into the geotextile earth retention structure. Although these methods are adequate to provide U.V. protection, corrosion of the bolts or metal anchors can reduce the life of the wall. The precast facing is also rarely attached accurately, so the resultant wall face may not be uniform in appearance.

Another wall face that has been used for geotextile walls is the option of casting a poured-in-place concrete face over the geotextile textile wall. This approach can result in a uniform aesthetic face, but it does require extensive forming and the associated high field labor and material costs. These additional costs can make walls of this type less competitive than other conventional wall types.

For wall locations where the retaining wall structure is located at the base of a hill or at the toe of an embankment, the cut or excavation required for the base of the wall may make the use of an MSE wall of any type impractical. Depending on the existing slope angle at the proposed wall site and in situ material of the sloping embankment, the excavation limits from the back of the cut may also be very large or require shoring in lieu of excavating massive amounts of material. For applications such as these, cast in place or tied back type retaining walls may be the current choice even though the cost of these walls exceeds the cost of typical MSE wall components.

Cast-in-place, cantilever walls for these applications typically have an extended footing in front of the wall and a shear key. The cost of the shear key and the extension of the footing in front of the wall to offset the lack of the footing behind the wall (under the wall fill) results in a substantially more costly wall than would be the case for a standard configuration cast-in-place wall. By the same token, if a tied back or other top down type of wall is selected for the cut wall site (e.g., due to the high cost of wall excavation), the end result will be a wall with a much higher unit cost than for a typical MSE or cast in place wall.

Another type of cast in place vertical cantilever wall application is for those walls along a channel or for bulkheads to act as erosion control structures along waterways or at the shore of other bodies of water. For channel applications where a vertical wall is required, if the area or right of way behind the proposed wall alignment is at a minimum, a front extension of the wall footing is required at the base of the wall. This situation, as for the previously described wall conditions, adds to the cost of the structure.

Both conventional cast in place concrete walls and precast wall systems are in use that provide free standing walls that are stationary prior to fill placement and are not dependent on fill interaction for stability, as is the case for MSE walls. The disadvantages of these walls are

shortcomings in fabrication and efficient construction techniques. These systems require an extensive use of formed, cast-in-place concrete for the completion of the wall construction. For example, wall panels having integral stems are connected to the cast-in-place wall foundation as the cast-in-place footing is poured. The wall panels for this system have to be braced in the field until the cast-in-place footing concrete has cured and obtained sufficient strength to allow the panels to be self supporting. The use of this extensive bracing and special forming for the wall foundation requires skilled workmen in the field to implement the connection of the panel to the wall base.

Another currently available free standing cantilever precast wall system is the "Port-O-Wall" product. For this system, the wall panels are also precast and are attached in the field to a formed cast in place wall footing. For this system the wall panel typically has voids in the bottom portion of the panel. The elevation of the void in the panels is located so that when the panels are erected in the field, the voids are encapsulated into the field concrete that is placed in the wall foundation. For the previously described system, there is a requirement for the rebar that is cast into the panel to react with the footing reinforcement and cast-in-place concrete to achieve the design wall stability. For the Port-O-Wall System, there is typically no exposed panel reinforcement, and the rebar in the footing is extended through the void in the panel prior to completing the placement of the footing concrete. For both of these systems, the wall panels are required to be braced until the footing concrete has reached sufficient strength to support the panel. The need to have the footing concrete cure is a disadvantage for either wall system for ease of construction or construction schedule. The bracing also adds time to the erection process. The need for the field concrete to reach design strength, so that the wall can withstand wall fill pressures, can be as long as 28 days before the wall fill can be placed behind the panels.

Another method that has been used extensively for cantilever wall applications is the double tee wall system that was developed by

Colorado Dept. of Transportation in the 1980's. For that design, double tee wall panels are placed on massive cast in place foundations to form a cantilever wall. The mechanism that is used to resist the overturning moments induced on the wall by the fill pressures is the extensive use of post tensioning rods. The rods are typically inserted through the tee stems of the double tee wall panels in the field and threaded into couplers cast into the wall foundation. To achieve the required accuracy for the placement of the couplers in the footing mandates, the use of special forming and highly skilled field personnel is required. Also, the installation of the post tensioning typically requires the use of special contractors in the field. As with the previous systems, should there be a void or incorrect application of grout at the connection point of the wall reinforcement the wall panel connection is subject to corrosion and premature failure.

Another precast wall system that simulates a conventional cast-in-place cantilever wall is disclosed in U.S. Patent No. 4,572,711, issued on Feb. 19, 1986 issued to Benson et al. This system requires the use of a precast double tee attached to either a precast or cast-in-place flat footing slab. The implementation of this design has similar shortcomings as those stated for the CDOT tee wall system previously described. Since the footing shown for that post tensioned combination is a flat slab, the size and thickness of the footing is required to be massive, similar to the CDOT cast-in-place footing. Also, the installation of the post tensioning requires specialty contractors.

In addition to the shortcomings stated for the above mentioned systems, all of these products, with the exception of the Benson patent, require special forms for the production of the wall panels.

Heretofore steel soil reinforcement, as well as flexible synthetic sheets of synthetic material, have been used for soil reinforcement for MSE walls. If steel is used, it is usually required to be galvanized or protectively coated to enhance the corrosion resistance. Also, an increase in the cross sectional area of the steel soil reinforcement

member is required so that the structure will still be in service for up to 50 years. This increase in cross sectional area is generally referred to as sacrificial steel in the industry. By adding additional steel area to compensate for the section loss due to corrosion, the cost of steel soil reinforcement is increased proportionally to the sectional area increase.

Due to the corrosion coating and an increased comparable sectional area for steel, there is a need for new products with enhanced corrosion resistance.

## Summary of the Invention

The present invention provides synthetic deformed bars (sdb's), retaining walls comprising sdb's, and methods of making retaining wall including sdb's. The sdb's are typically solid, rigid bars are can be of any suitable sizes and strength. Sdb's can be used as tie rods, as anchors, as soil inclusion members, as tensioning members, and the like.

In accordance with one aspect of the present invention, a full height precast panel MSE wall system is provided. The MSE wall system generally includes an assembly of wall panels, a foundation, confined face layers forming a mechanically stabilized earthen wall fill (MSE), and a plurality of sdb's disposed or imbedded in the MSE. The wall panels are typically precast. The foundation can be, for example, cast-in-place or precast, and may optionally be elevated with respect to the bottom layer of the MSE wall. The sdb's can be attached wall panels at attachment points to position the wall panels in a stable, substantially vertical plane. The MSE can optionally be separate from or in contact with the wall panels.

In certain embodiments, the MSE wall system can use permanent precast wall panels that correspond to the height of the MSE, or that are in incremental heights, the total of heights of which equal or exceed the height of the MSE. Full height wall panels are typically not subject to significant earth loading by the retained soil. The synthetic deformed

The combination of the vertical bars restrained by the U-bars can optionally form a plane at the face of the wall, without the use of an external forming system. Because the vertical grid can be established with bars of varying lengths convenient for wall construction and plan layout, a grid mat of much smaller spacing can be placed behind the vertical grid of horizontal and vertical disposed bars. This smaller grid (or mesh mat) along with a geotextile or comparable flexible fabric can form the closed face of the MSE wall and can prevent soil particles from falling away from the separate MSE wall.

In certain embodiments, such a field assembly process can be followed until the height of the MSE wall corresponds to the panel attachment elevation. At the anticipated panel joint, a separate sdb with a threaded end can be placed in the fill. A plate can be attached to the threaded end of the bar. The plate optionally can be attached to the adjacent panels as they are placed. The panels can thereby be secured to the separate MSE wall. Typically, the panel attachment elevation is close to the maximum MSE wall height, so that the MSE wall effectively acts to surcharge or consolidate the in situ foundation material at the base of the wall prior to the attachment of the fascia panels to the MSE wall.

In other embodiments, precast double Tee retaining walls are provided. Such walls can include, for example, an assembly of wall panels attached to similarly shaped concrete foundation tees, shaped vertical tee stems formed with a horizontal and vertical bearing surface for contact with the horizontal and vertical bearing surfaces of the foundation tee stems; precast concrete tee stems forming a foundation means; and shaped vertical tee stems formed with a horizontal and vertical bearing surface for contact with corresponding vertical and horizontal bearing surfaces of said foundation tee stems. Synthetic deformed tension bars, high strength steel threadbars and/or high strength steel strand cables can be used to attach the tee members. In another embodiment, double tee

wall panels are attached to deadmen placed in excavated trenches or in slots within in situ material behind tee wall assemblies.

In a related embodiment, a segmental, anchored, generally vertically inclined or variably inclined precast retaining wall system is provided. The wall system can include, for example, foundation means; an assembly of base wall panels attached to the said foundation means; shaped vertical tee stems formed with a horizontal and vertical bearing surface; an assembly of upper subsequent tiers of wall panels stacked on the base tier panels; and straight or U-shaped sdb's attached to said base wall panels and to the upper tier wall panels; base and upper flat wall panels placed between base and upper wall support panels. Geosynthetic sheets can be placed with backfill material behind the wall support panels and flat panels.

These and other embodiments are further described by the following description and drawings.

**Description of Figures**

Fig. 1 Isometric Showing SDB U-Shaped Soil Reinforcement.

Fig. 2 Vertical Cross Sectional View of Partially Completed SDB MSE Wall.

Fig. 3 Isometric of Partially Completed MSE Wall with Panel Installed.

Fig. 4 Vertical Cross Sectional View of Completed Fascia Panel MSE Wall.

Fig. 5 Isometric Showing Void End Connector SDB MSE Wall with Panel Installed.

Fig. 524 Isometric of Semicircular Face MSE Wall.

Fig. 498 Vertical Cross Sections of Partial Void Full Height MSE Wall.

Fig. 499 Vertical Cross Section of Braced Full Height Panel Wall.

Fig. 6 Partial Elevation View of Multiple Panel MSE Wall.

Fig. 7 Vertical Section of Multiple Panel MSE Wall.

## Detailed Description of Specific Embodiments

The present invention provides synthetic deformed bars (sdb's), retaining walls comprising sdb's, and methods of making retaining wall including sdb's. The sdb's are typically solid, rigid bars and can be of any suitable sizes and strength. Sdb's can be used as tie rods, as anchors, as soil inclusion members, as tensioning members, and the like. The sdb's are typically generally elongate and can have any suitable cross-sectional shape, such as, for example, a generally circular, ellipsoidal, square, rectangular, polygonal or other regular or irregular cross sectional shape.

Sdb's, according to the present invention, are typically substantially solid and composed of a corrosion-resistant synthetic (i.e., non-metallic material), such as, for example, polyester, vinyl ester, epoxy and epoxy derivatives, urethane-modified vinyl ester, polyethylene terephthalate, recycled polyethylene terephthalate, and the like. Suitable materials can also include combination of any of these. The synthetic resin can be a composite fiber material, such as a combination of a synthetic resin and a fiber reinforcement. Suitable fiber reinforcements are typically non-metallic and include, for example, E-glass, S-glass, aramide fiber (e.g., KEVLAR), carbon fiber, ceramic reinforcement and the like, or combinations of any of these. Suitable fiber composite materials are, for example, PSI Fiberbar (Polystructures, Inc., Arkansas) or C-Bar (Marshall Industries). In some applications, the bar can be coated with a corrosion or moisture resistant material.

SDB's have adequate deformations for bonding to grout or other bonding material, or for use as soil inclusion members. As used herein, deformations can be corrugations, dimples, protrusions, and the like, on the circumference of the bar. Such deformations provide a larger surface for bonding of the bar surface to cement, concrete, and grout. e.g., (hereafter generally referred to as "grout"), soil, and the like. Such increased bonding area allows a stronger bond to be formed between the bar and the grout or soil, thereby taking advantage of the load capacity of the bar. The deformations on the surface of the bar can optionally form a continuous repeating pattern on the surface of the bar. In such an embodiment, the deformation can have a generally relatively consistent spacing and depth (or height) from the bar's surface to provide a predictable field bonding characteristic. The deformations in the SDB can also facilitate the connection of attachment devices, such as couplers, as may be required for in situ soil reinforcement. The SDB can also have a flared end or a threaded end.

In certain embodiments, the sdb's have significant surface deformations comparable to that of steel rebars, which provide pullout resistance of

the sdb's which is substantially higher than that of many other types of soil reinforcement currently in use. Sdb's also have lighter weight and higher strengths with equivalent bond strengths of concrete or cementatious grout than metal bars of the same cross-sectional area. Due to the lightweight and high tensile strength, the bars can be rigid and exhibit a high bending moment capacity .

Sdb's, according to the present invention, can include a variety of mechanical ends. For example, such mechanical ends can facilitate use of the sdb's for soil anchoring as described in PCT/US01/05733, and in U.S. provisional patent application Number 60/184,049 (the disclosures of which are incorporated herein in their entirety). In certain embodiments, sdb's with significant deformations of the cross-sectional area with deviations over the length of the sdb can have a high bonding strength between the sdb and the surrounding material. The associated pulling resistance to remove the sdb from a surrounding medium will be significant. This property is useful not only if the surrounding material is concrete or a cementatious grout, but also applies to other types of surrounding material, such as soil.

In certain installations, it may be desirable to structurally integrate the wall face to the sdb's by "lapping' face bar reinforcement inserted into the drilled shaft at the face of the wall following the installation of an sdb nail assembly. For such a configuration, the inserted bar reinforcement length is typically determined by the bond length to obtain the full strength of the sdb. Since it is feasible to visually inspect the shaft void at the face of the wall, the use of steel bars may be acceptable for these applications, since the probability of complete encapsulation of the bars with the grout is quite high. With complete cover of the bars with grout, the usual corrosion concerns with the use of steel bars is minimal, since their use with this option is only at the wall face.

Steel bars can optionally be used to transfer the sdb load to the wall face. For example, a bar/steel plate assembly or hairpin bars with an

approximate 180° bend can be used. The bar/plate option typically requires that the steel reinforcing bars or other deformed bars (e.g., thread bars) be structurally attached to a plate prior to inserting into the shaft. For a hairpin bar (e.g., having a 180° bend) inserted into a shaft void, typically steel deformed bar reinforcement or high strength cable (e.g., stressing strand) is pre-bent prior to insertion. For either option, face reinforcement, parallel to the proposed final wall face, is placed either behind the plate or through the hairpin bars (at the 180° bend). These face bars can typically be placed in an orthogonal pattern and integrated with adjacent reinforcement of the soil wall concrete face, although other patterns are possible and within the scope of the present invention.

In certain embodiments, a fascia panel MSE system is provided. Referring to Figure 1, a schematic, isometric view of an assembly 100 of a separate MSE wall is shown. The assembly utilizes synthetic deformed U-bars 104 for soil reinforcement. U-bars 104 are shown placed in an alternating pattern and are generally placed in horizontally disposed planes, although other patterns are possible. The U-bars 104 typically can be placed in wall fill soil or other suitable fill as that fill is placed. For clarity in Fig. 1 to show a relative position and arrangement of the U-bars, the MSE wall fill is not shown. The alternating pattern, wherein each horizontal layer of U-bars 104 is uniformly displaced from the locations of the previous U-bar 104 layer, results in a uniform grid pattern at the wall face. The use of U-bars, rather than using single bars, results in two soil reinforcement bars for each field placement within the soil mass (not shown), which facilitates rapid wall construction. The skilled artisan will appreciate, however, that single bars also can be used.

Vertical face bars 102 can be placed on the inside of the exposed front section 106 of the U-bars 104. The vertical face bars 102 are shown extending a vertical distance 103 above a typical U-bar 104. The vertical orientation of the U-bars 104 can be maintained by the stationary position of the lower U-bar 104. A typical material for the

vertical face bars 102 is a corrosion-resistant material, such as a synthetic deformed bar or other suitable material that can be fabricated as bars. Such bars typically have a uniform cross section with suitable bending strength characteristics for wall face loads.

Figure 2 depicts a vertical cross sectional view of a partially completed wall assembly 100 shown in Fig 1. View a. in Fig. 2 depicts an optional face grid 114 placed at the face of the first fill layer 132. A flexible woven face material 116 can be placed behind the face grid 114. The face grid 114 and the flexible woven material 116 can be restrained from horizontal outward displacement by the vertical bars 102. Partial fill layer 134 is shown placed over U-bar 104, which holds U-bar 104 in a stationary position. The interaction of the fill layers encapsulating the U-bars 104 can result in a stationary position of the U-bars 104, such that the vertical bars 102, the optional face grid 114, and the optionally flexible woven face material 116 can be restrained from outward horizontal movement.

The top portion of Figure 2, view b., shows optional wall fill placed in the vertical sectional view of wall assembly 100 shown in Fig. 1. Free draining face fill 136 is shown placed behind the flexible woven face material 116 in view b. Placement of the free draining face fill 136 can be implemented by laborers or with conventional earth moving equipment. As the subsequent, upper fill layer 135 and the partial fill layer 134 are placed over U-bars 104, the U-bars 104 can be restrained from movement by the effect of the fill placed around the U-bars 104. Additional layers of U-bars 104, as needed, can be placed over vertical bars 102 with the front section 106 of the U-bars 104 positioned on the vertical bars 102 to the proper wall alignment as wall placement proceeds toward the design height of the wall.

An exemplary embodiment of subsequent placement of vertical face bars 102 of typical vertical cross sections of a separate MSE wall assembly 100 is shown in Figure 2 at various construction stages. U-bars 104 are shown vertically displaced with vertical face bars 102 placed behind and

extending above the U bars 104 in both views "a" and view "b". View "a" shows the initial fill layer 132 placed with U bars 104 placed under and above initial fill layer 132. Partial fill layer 43 placed over U bar 104 can stabilize and immobilize U bar 104. Face mesh 114 and the face fabric 116 are shown in place behind face bars 102. Face bars 102 in combination with face mesh 114 and face fabric 116 can hold the wall backfill material within the stabilized MSE wall mass.

Subsequent fill layer 135 is shown placed in view "b" in Figure 2. Prior to placing fill layer 135 the triangular fill 136 can be placed as shown behind face fabric 116 and under U bar 104. This efficient placement of triangular fill 136 is possible due to the rigid nature of U bar 104. For other flexible strip or sheet reinforcement in current use for other MSE walls it is impractical to place fill as shown for the triangular fill 136. Subsequent fill layers 135 and placement of U bars 104, vertical bars 102 and face fabric 116 proceed to the desired wall height as can be appreciated by the skilled artisan.

A partially completed isometric view of wall assembly 100 is shown in Figure 3. Panel 140 is shown placed on foundation 24 attached at the bottom to angle clip 162 and at the back side of the panel 140 to a channel connector 80 attached to a threaded end extension sdb 61. U bars 104 ands U bend bars 34 are shown installed in an alternating pattern in vertically disposed layers. The fill layers surrounding the soil reinforcement has been omitted from the isometric view in Figure 3 for clarity.

Referring to Fig. 4, an exemplary embodiment of a substantially completed vertical wall section is shown. A plurality of U-bars 104 are shown encapsulated with completed fill layers 130, 135, 137, 139 are shown sequentially placed to form a stable MSE wall. A full height face panel 140 is shown attached to the MSE wall assembly 100 with a threaded end extension connector sbd 61 attached to a channel connector 80. The channel connector 80 can be attached to the back of the panel 140, such

as, for example, as disclosed in U.S. Patent No. 6,238,144 (the disclosure of which is incorporated herein by reference). The panel 140 is shown placed on foundation pad1 24 and secured to conform to the proper wall alignment by a base clip 162, a base bolt 166 passed through a face plate 166 and threaded onto a nut 167. The materials for parts 162, 163, 164, 166 and 167 can be, for example, a commercially available synthetic material or metal or steel, with a conventional corrosion coating applied (e.g., galvanizing), as desired. The embankment fill 170 is placed at the top of the wall over the fill layer 139 and behind the full height face panel 140. Optionally, the embankment material 170 can be prevented from migrating into the void between the back of the full height panel 140 and the face of the separate MSE wall assembly 100 by, for example, a top membrane 168. Suitable material for the top membrane 160 can be, for example, a flexible high strength synthetic material such as PVC or HYPALON, and the like. The separation distance 161 and the height of the full height face panel 140 determine the area or volume of the void between the panel 140 and the face of the separate MSE wall assembly. This void volume can either be left unfilled or can be filled with a variety of light weight fill types, depending on the wall design requirements.

Figure 5 depicts an embodiment of partially assembled MSE wall with a full height panel attached to the separate MSE wall 10. A threaded end extension sdb 61 as described in PCT/US01/05733, filed February 22, 2001, and in U.S. provisional patent application Number 60/184,049. The threaded end extension sdb 61 is attached to a channel connector 80. The channel connector 80 can be subsequently attached to the back of panel 140 with bolts or other suitable connection mechanism. The panel 140 is shown placed on an elevated pad 160. The elevated pad 160 can be placed on confined fill MSE layer(s) 151, can be placed under and in front of the separate MSE wall assembly 10. Typical materials for the panel 140 and the elevated pad 160 are concrete or other durable, rigid materials. The confined fill MSE layer faces can be formed with geotextile or other synthetic flexible soil tensile inclusion materials known in the art.

Another exemplary embodiment for a separate MSE wall assembly 101 is shown in the isometric view of a typical wall construction in Fig. 5. The use of a void sdb connector assembly 34 (as disclosed in PCT/US01/05733 and in U.S. provisional patent application Number 60/184,049) is shown as the tensile soil inclusion member. Vertical bars 102 can be placed through the void connector 34, comparable to that described for the U-bars 104 previously described. For certain wall applications, the use of the U-bend void connector sdb 34 can have field or other economic advantages by incorporating two sdb's by having a U-bend at the rear of the end of the double bar assembly. As with the U-bar 32, the U-bend void connector sdb 34 facilitates efficient field placement because two bars are effectively placed with each bar assembly set. Additionally, the use of the U-bend sdb 34 can provide additional tensile capacity for the individual U-bend void connector sdb 34, due to the deadman effect of the U shape within the fill. The tensile force required to pullout or pull the U-bend void connector sdb 34 within the backfill mass is greater than that of the sdb 34 since the U-bend portion has to shear through the surrounding compacted soil encapsulating the U-bend void connector sdb 34. This increased pullout capacity can also allow for the use of shorter U-bend void connector sdb's 34, compared to the length of straight bars for a given wall design. The full height panel 140 can be attached to the separate MSE wall as previously described. Other types of attachment devices can also provide equivalent means of attaching the full height panel 140 to the separate MSE wall 101 or 100.

Another option for forming the separate MSE wall for the fascia panel wall system is the curved closed face MSE wall utilizing sdb's. For this MSE wall option, the face (exposed portion) of the sdb's used for tensile inclusion members typically has a radial or semi-circular shape. The sdb's can be arranged in an alternating pattern in a generally horizontally disposed plane within the wall fill. As the sdb's are typically installed in sequential layers proceeding from the base of the wall, flexible corrugated sheets are placed to conform to the face curve

of the sdb's within the semicircular arc of adjacent sdb's. Suitable sheet material is, for example, that used for building roofing or building cladding. Due to the corrugations of the sheet steel or aluminum material, the sheets are flexible to facilitate bending in conformance to the face curve. Conversely the sheets exhibit a high bending moment resistance for loads applied perpendicular to the long axis of the sheets. Since this is the load condition for the curved wall face, corrugated sheets can be effectively used to span the vertical distance between the horizontal layers of the curved faces soil reinforcement. For permanent fascia panel application, the corrugated sheeting material can be aluminum, plastic, fiberglass, or other corrosive resistant material. For temporary wall applications, steel soil reinforcement, such as deformed steel reinforcement bars bent to the curved shape, can be used with steel corrugated sheets.

Temporary wall applications would typically be used to contain embankments on construction projects due to logistical phasing needs of specific projects.

Figure 524 shows an isometric view of a partial front elevation of an option for the semicircular closed face MSE wall 418. The previously described wall system 100 shown in Figure 5 shows U-shaped sdb's 32 for the separate closed face MSE wall 418. Figure 524 shows the use of semicircular sdb's 420 arrayed in generally horizontally disposed planes that are vertically displaced. Shown behind the generally vertically disposed stack of semicircular sdb's 420 are corrugated sheets 422. Suitable material for the corrugated sheets 422 are aluminum, steel, or synthetic material such as fiberglass. The corrugations 424 (depicted as vertical lines) allow the corrugated sheets 422 to conform to the curved shaped of the semicircular sdb 420. Additionally, the corrugated sheets 422 perform similarly to the vertical sdb's 102 (as described for wall assembly 100) as the corrugated sheets 422 are free standing and can be extended to cantilever distance 426 above the top of an in-place semicircular sdb 420. The ability to cantilever or extend the corrugated sheet 420 above previously backfilled semicircular sdb's 420

is a significant construction convenience. Either straight or U-bend sdb's can be equally used for soil reinforcement or to restrain the corrugated sheets 420, and can also be used with the addition of other geosynthetic soil reinforcement within the layers of semicircular sdb's 420 or semicircular U bend sdb's 421 without affecting the operation of the present invention.

For temporary applications the semicircular face separate MSE wall 418 can utilize conventional steel deformed bars to secure the corrugated sheets 420. Steel bars (not shown) can either be straight or have a closed type U-bend within the MSE wall without affecting the operation of the current invention.

Additionally shapes other than smooth semicircular curves shapes can be used without conflict with the present invention. Triangular or other face bend shapes (not shown) are other potential shapes that allow the use of flexible sheeting with a high bending capacity.

Due to the rigid nature of sdb's, it is feasible to utilize the bars for direct connection to full height panels. One method is to utilize a separate closed face MSE wall for the lower portion of the wall so that the need to temporarily brace the wall panel is minimized or eliminated. By providing a partial height, separate closed face sdb or sdb reinforced MSE wall in combination with other geosynthetic fabrics or geogrids built to at least one third of the overall height of the wall, the full height panel can be supported from horizontal sdb's placed within the separate MSE. Following placement of a full height panel on the foundation, and while the panel is held by appropriate lifting devices, sdb's extending from lower the separate MSE wall can be attached to full height panels. The lifting devices can then be removed from the panel, since the panel is stable and held in a vertical position by the restraining effect of the sdb's imbedded in the separate MSE wall.

Placement of self-compacting fill within the void between the separate

closed face MSE wall and the back of the panel up to the elevation of the top of the partial height MSE wall precedes the attachment of the remainder of the sdb's, either void end or threaded end extensions sdb's, and proceeds in correspondence to the fill placement to the top of the wall panel.

Since the sdb's are rigid and have a high bending movement capacity, their use has distinct advantages compared to the use of flexible soil reinforcement that is in current use to for attachment to full height panels. Since the bars will resist bending due to their rigid nature if the wall fill settles or moves downward with respect to the wall panel the likelihood of a shear failure at the connection of the sdb to the tee panel is unlikely. Additionally the use of the connector options that are described in the following various multiple panel wall facing embodiments for use with the current invention allow for vertical differential settlement without introducing noticeable shear at the connection.

Another option for full height panels with direct attachment to sdb's imbedded in the wall fill is to temporarily brace the panel in a vertical orientation. The stabilizing effect of the brace along with the connection of the full height panels to the foundation allows the careful placement of wall fill and sdb's without effecting panel alignment. The braces can be removed when the fill height and sdb's within the fill are connected to the panel when the fill height reaches approximately one third of the wall height. The remainder of the sdb's and wall fill can then be completed to the design height. As with the previously described embodiment, the sdb's and fill can exhibit limited vertical settlement with regard to the panel elevation due to the use of the connections described herein for other embodiments.

Referring to Figure 498 three vertical cross sectional views of a typical partial void fill full height panel MSE wall assembly 105 at various construction phases are shown. View "a" in Figure 498 shows a partial separate closed face MSE wall 103 placed over a foundation pad

24. The partial closed face MSE wall 103 is shown utilizing U bend sdb's 104 for soil tensile inclusion members. Alternatively, void end connectors sdb's 32 or 34, (although not shown) can be equally be used for tensile inclusion members. Vertical bars 102 restrain the face mesh 114 and geotextile sheet 116.

Referring to view "b" a full height panel 28 is shown attached to the threaded end extension sdb 40. Full height panel 28 is also attached to base angle clips 162 at the foundation pad 24. Full height panel 28 would typically be placed following placement and cover of threaded end extension sdb 40 by partial fill layer 43 which secures and immobilizes threaded end extension sdb 40.

View "c" in Figure 498 shows a completed partial void full height panel MSE wall assembly 107. Additional threaded end extension sdb's 40 are attached to full height panel 28 above the partial height closed face MSE wall 103. Geosynthetic sheets 354 are also shown placed between threaded end extension sdb's 40. The optional use of geosynthetic sheets 354 along with various sdb soil reinforcement members may be cost effective and installed within the MSE for certain wall applications without conflict with the present invention.

Vertical sectional views of a braced full height panel MSE wall assembly 109 are depicted in Figure 499. In view "a" a full height panel 28 is set on and attached to foundation pad 24. A temporary erection brace 59 is attached to full height panel 28 to maintain the orientation of full height panel 28 that can also be attached to foundation pad 24 with base angle clips 162.

View "b" in Figure 499 shows threaded end extension sdb's 40 attached to full height panel 28. Although not shown the use of other sdb's such as the void end sdb 32 can alternatively be used for attachment to the full height panel 28. The optional use of geosynthetic sheets 354 for additional soil reinforcement are also shown placed within the wall fill. Additional MSE fill layers 139 in conjunction with sdb's 40, 32,

or 34 attached to full height panel 28 will form a completed braced full height panel wall assembly 109 (not shown). Following placement of reinforced MSE fill layers 139 to a wall elevation of between one third to one half of the wall height (or other height increments) the temporary brace 59 can be removed and the remainder of the sdb's and fill layers 139 placed to the wall height.

In accordance with another aspect of the present invention, the use of sdb's to retain multiple facing panels with varying shapes or interface details is also provided. Rigid sdb's used for soil reinforcement allows for partial fill placement prior to sdb soil reinforcement placement adjacent to and in contact with the backside of multiple facing panels. Placing wall backfill under the sdb's following panel placement can reduce or eliminate the need for temporary bracing or shimming, or interlocking of facing panels, which results in construction time savings. Size, shape, or panel interface details for the present invention are not significant for the operation of the present invention and any suitable shape or panel interface can be used in conformance with the use of sdb's described for soil reinforcement. The panels can be attached to the sdb's with any suitable attachment mechanisms known to the skilled artisan as well as those described herein.

Referring to Figure 6, a partial elevation view of an exemplary assembled wall face 10 is depicted. Because the assembled wall face 10 is not dependent upon the shape or size of the precast facing panels, various shapes and sizes of panels can be used, as shown. Progressing from the left to the right side of the drawing, a rectangular panel 20 is shown next to a cruciform shaped panel 22 with small filler panels 24. The cruciform panel 22 is shown placed over a square panel 25. Next to the square panel 25, a triangular panel 26 is shown under a diamond panel 27. Above the diamond panel 27, a partial trapezoidal panel 28 is shown next to a full height trapezoidal panel 29. Numerous other panel shapes can be used, and in any suitable order or configuration, as will be appreciated by the skilled artisan.

Figure 7 depicts an example of a vertical cross sections taken through a typical MSE wall, such as the partial elevation shown in Fig. 8. Such an MSE wall can be constructed in accordance with the present invention. A MSE wall assembly 12 is shown being constructed. The face panels 37 are shown attached to soil reinforcement void end connector sdb's 32 or U-bend void connectors sdb 34 placed generally perpendicular to the panels 37 and disposed in a substantially horizontal orientation between layers of mechanically stabilized backfill material (not shown for clarity).

Three typical sequential sectional views of a multiple panel assembly 12 during a wall construction are shown in Figure 7. View "a" shows U-bend void connector sdb's 34 attached to panel 37 prior to placement of a subsequent face panel 37. View 'b" depicts the subsequent panel 37 placed and connected to sdb 32. Void end connector sdb's 32 (or other sdb's that can be used) can be prevented from movement or is relatively immobile, due to the effect of the partial layer of stabilizing fill 241. Since void end connector sdb 32 is relatively immobile, panel 37 is similarly relatively immobile and prevented from rotation or horizontal movement. The fill void 239 behind panel 37 (the volume of fill) shown as a phase of the wall construction is a result of the use of rigid sdb's for panel attachment.

Figure 7, view "c", shows the remaining fill layer 243 placed behind void end connector sdb 32. The complete encapsulation of the U-bend void end connector sdb 34 is possible due to the stiff or rigid nature of the sdb 32 or U-bend void connector sdb 34. (In other embodiments, the sdb is not completely encapsulated.)

Figure 8 shows three views of a typical void end connector sdb 32 attached to the panel 37. The top view "a", shown in Figure 8 is a top view of the panel 37 in the vicinity of the attachment location of the void end connector sdb 32 to the panel 37. The top view "a" shows the void end connector sdb 32 with a void connector 40 attached to the panel

37 at the fill side 39. A cap pin 42 is shown inserted through a strap insert 44 cast into the fill side 39 of the panel 37. The void connector 40 is described in PCT/US01/05733 and in U.S. provisional patent application Number 60/184,049. Typical materials for the strap insert 44 and cap pin 42 are high strength corrosion resistant materials, such as for example, aluminum, stainless steel or a synthetic material such as a plastic polymer.

The center view "b", shown in Figure 8 depicts a partial rear elevation view of the panel 37 at the sdb attachment location. The cap pin 42 is shown inserted through the void connector 40 through both the top and bottom of the strap connector 44. The installation position of the sdb 32 is shown in close proximity to the top portion of the strap connector 44.

The lower view "c" shown in Figure 8 depicts a vertical section view of the panel 37, as shown by the section lines on view "b" in Figure 6. Compressible material 46 can be placed under the void connector 40 with the cap pin 42 inserted through the compressible material 40. The thickness 48 of the compressible material 46 corresponds to the vertical settlement distance 48 that is allowed by the SDB 32, should vertical settlement occur between the panel face 37 and the MSE fill mass. Vertical relative displacement between the sdb 32 or U-bend void connector sdb 34 and the panel 37 is achievable due to the rigid nature of the sdb 32 or U-bend void connector sdb 34. Suitable materials for the compressible material 46 include, for example, closed cell foam or other types of corrosion resistant materials, as are known to the skilled artisan.

Referring to Figure 9, a top view "a", partial elevation view "b", and section view "c" are shown of a void end connector sdb 32 attached to a panel 37. View "a" shows a top view of a panel 37 at the location of an attachment point of the void end connector sdb 32. The dotted lines show the outline of a recess void 50. The center view "b" depicts a partial rear elevation of panel 37 at the attachment location of the

void end connector sdb 32. The recess void 50 shows the panel pin 52 extending above the top of the void end connector 40. The compressible material 46 is shown placed under the void connector 40. The panel pin 52 material can be formed of a synthetic material, aluminum or other suitable corrosion-resistant metals.

The lower portion of Figure 9, view "c", shows a vertical cross section of attachment of the sdb 32 to the panel 37. The void end connector 40 is shown placed over the panel pin 52 and on top of the compressible material 46. The vertical settlement distance 48 is typically the allowable vertical settlement distance.

Figure 10 shows a partial top and rear view elevation views of a panel 37 at the attachment location of a threaded end extension sdb 61 to the panel 37. The upper portion of Figure 10, view "a", shows the threaded extension 61 perpendicular to the panel 37 with the outer adjusting nut 64 against the sliding connector 62. The threaded extension 61 is described as PCT/US01/05733 and in U.S. provisional patent application Number 60/184,049.

The partial rear elevation, view "b", shows the threaded end extension 61 attached to the panel 37 at the sliding connector 62. The recess void 60 is shown and is formed by using a blockout as the panel is cast.

Figure 11 shows four exemplary views of the sliding connector 62. View "a" shows a partial elevation view of the sliding connector 62. The threaded extension 61, with outer adjusting nut 64 threaded onto the threaded extension 61, is shown attached to the sliding connector 62. The sliding clearance distance 67 is typically slightly greater than the diameter of the threaded extension 61. The difference between the diameter of the threaded extension 61 and the sliding clearance distance 67 is typically sufficient to allow vertical movement of the threaded extension 61 in the sliding connector 62.

View "b" of Figure 11 shows a vertical cross section cut through the sliding connector 62, as indicated by the left section lines in view "a" of Figure 11. The threaded extension 61 is shown secured to the sliding connector 62 by the outer adjusting nut 64 and the inner adjusting nut 66. The imbedded arms 63 of the sliding connector 62 are cast into the panel 37 a sufficient distance to form a competent bond to the material of panel 37 (e.g., concrete). The depth of the access void 60 is sufficient to facilitate attachment of the inner adjusting nut 66 to the threaded extension 61. Behind the sliding connector 62 and under the threaded extension 61, the compressible material 46 is shown. The vertical settlement distance 48 is typically the amount of vertical settlement that can be accommodated by the sliding connector insert 62.

View "c" of Figure 11 shows a vertical section through the center of the threaded extension 61, as shown by the section lines on view "a". The sliding spacer 69 is shown with the threaded extension 61 inserted through the circular void 71 in the sliding spacer 69. The clearance distance 67 of the sliding spacer 69 is slightly greater than the thickness 65 of the sliding coupler 62. The dimensions of the sliding spacer 69 allow the threaded end extension  sdb 61 to be secured to the panel with the inner adjusting nut 66 and outer nut 64 positioning panel 37 in a substantially vertical plane. The orientation of the sliding coupler 62 and the compatible width dimension 65 of sliding spacer 69 allow for vertical movement of the threaded extension 61 relative to the panel 37.

View "d of Figure 11 shows a vertical section through the sliding spacer 69, as indicated by the section line on view "c". The thickness of the sliding spacer 69 is typically slightly smaller than the clearance distance 67 of the sliding coupler 62. The addition of the compressible material 46 in the recess void 60 prevents wall fill material (not shown) in view "b" from migrating to the recess void 60 and reduces the possibility of inducing excess shear or bending loads on the threaded extension 61. The compressible material 46 typically has a durometer rating to allow the portion of the threaded extension 61 in the access

void 60 to displace the compressible material 46 without inducing excess shear or bending loads on the threaded extension 61.

Threaded extension 61 can displace downward due to the rigidity of the threaded extension 61 (bending moment resistance) and, in conjunction with the combination of the sliding spacer 68 assembled as shown, a mechanism is provided for maintaining an essentially vertical position for the panel 37 during construction and for the completed wall, while allowing free vertical displacement of the threaded extension 61 with respect to the stationary position of the panel 37.

Certain applications may require that the multiple facing panels be horizontally offset. Therefore rather than the upper and lower edges of adjacent panels being in total contact forming a planar face, upper subsequent rows of facing panels can be horizontally offset from each other. For configurations of the this type, the portion of wall fill under the planned horizontal offset location of the adjacent upper panel is required to be placed and compacted to the proper base elevation and grade of the panel. Following placement of the offset panel and attachment of at least one sdb to securely position the offset panel, the placement and construction procedures for this optional embodiment proceed as previously described for the multiple panel system.

Figure 518 shows three side sectional views of a horizontal offset multiple panel MSE wall 13 being constructed. View a. shows a base multiple panel 37 secured to void end U bend connector sdb's 34. View b. shows a face multiple panel 37 with a horizontal panel offset 404 reflecting the variable offset between adjacent multiple panels 37. A straight void end connector sdb 32 is shown secured with partial backfill 241 attached to panel 37. The fill void 239 behind panel 37 has not been backfilled at this stage. View c. shows adjacent wall backfill 243 placed under the rigid sdb 32 and behind panel 37 following attachment of the void end connector sdb 32.

Another economic and unique wall facing option is that of utilizing precast concrete roof ballast pavers or concrete roof tiles for wall facing. Such facing, although not in current use for retaining wall applications, can be lightweight, strong, and with the colorful appearance of such products which are currently used for roofing applications. Typically, void end connector sdb's can be used although other connection options can be used to secure the paver facing and will be and be in conformance with the present invention. For this wall facing, the voids in the sdb's are generally horizontally disposed, allowing for the placement of horizontal rods between sdb's placed within the wall fill in the same generally disposed horizontal plane.

By placing horizontal bars, such as sdb's, aluminum, corrosion resistant steel, or equivalent strength synthetic bars, in adjacent layers of void end sdb layers, an essentially vertical or inclined plane can be formed between subsequent layers of sdb soil reinforcement. By installing concrete ballast pavers or concrete (or other cementatious or clay) roofing tiles behind the horizontally disposed bars between the sdb's, an essentially vertical or inclined plane is formed by the pavers or tiles. The paver or tile tier wall face height roughly corresponds to the vertical layer height of the sdb reinforcement. Suitable SDB's include straight or U-shaped bars for soil reinforcement. In addition, such sdb's can be integrated with other geosynthetic soil reinforcements If deemed appropriate for certain wall applications without affecting the operation of the invention.

For sdb walls utilizing concrete ballast pavers or tiles for wall facing, the individual tier heights will either typically closely correspond to the long dimension or the short dimension of the paver or tile. In addition, the individual tiers can be essentially vertical, or can be installed leaning outward or in a reverse batter orientation. A horizontal offset between alternating layers of sdb layers is also typical for this wall option. The resulting exposed horizontal layer of wall fill between layers of sdb's provides potential planting space within the wall face. If a reverse batter inclination is used for each

tier of tiles or pavers, an essentially vertical or steep wall face results which creates adequate space for installation of landscape materials between tiers with a minimum wall face batter. The effect of the plants and the colorful face provided by the variable earth tone colored concrete facing, results in a low cost, attractive, plantable MSE wall system.

Figure 520 depicts an isometric view of a partially constructed horizontally offset paver MSE wall system 406. Void end connector sdb's 32 are shown placed in a generally disposed horizontal plane similar to the pattern previously described for the separate MSE wall 101 for the fascia panel 100 wall system. In Figure 520 horizontal load bars 408 are shown inserted through the void end connector sdb's 32. Placed behind and bearing on the horizontal load bars 408 are precast concrete ballast roofing pavers 410. Each row of the array of precast concrete ballast roofing pavers 410, placed edge to edge are behind and bearing on the top and bottom horizontal load bars 408. The planting tier 412 between the rows of precast concrete ballast pavers 410 provide an area for landscape materials (not shown) to be placed.

The horizontal offset sdb MSE assembly can also utilize a flexible mesh fabric face 116 (not shown) in lieu of the concrete ballast roofing pavers. The use of flexible mesh/ fabric face 116 for wall facing has been previously shown and described in the fascia panel MSE system 100. Concrete roof tiles (not shown) are also equivalent facing for the horizontal offset precast concrete ballast paver MSE assembly 406.

Figure 522 shows an oblique perspective of a reverse batter horizontal MSE wall assembly 414. Void end connectors sdb's 32, horizontal load bars 408 and precast concrete roofing ballast pavers 410 are shown in a similar manner to what was shown on the previous Figure14. The lower layer of each paired row of the generally horizontally disposed void end connector sdb's 32 is horizontally displaced from the adjacent upper layer of void end connector sdb's 32 by the reverse batter outward displacement 416. The reverse batter outward displacement 416 results

in an overall wall face batter (not shown) that is steeper than would be the case for an horizontally offset paver MSE wall system 406. The reverse batter horizontal MSE wall assembly 414 then offers equal width planting tiers to the horizontally offset paver MSE wall system 406 with a steeper face batter.

In another aspect, a double tee cantilever wall is provided. Such a wall can be used, for example, for narrow right of way wall locations or at the base of an existing sloping embankment. Precast double tees can be used for the base of the cantilever wall and the face of the wall. These tees can be fabricated for many structural applications, such as for example, bridge decks of roof structures. Many tee configurations are known to the skilled artisan and can be used in accordance with the present invention. Optionally, the use of double tees for the wall base or foundation of the wall can eliminate the need for a cast-in-place foundation for the wall panels.

In certain embodiments, the tee sections can have equivalent bending to that of a massive rectangular footing with a fraction of the concrete volume. Due to the height of the base tee stems, the base of the wall panel is typically at a higher elevation than the base of a comparable cast-in-place wall. Therefore, the loads on the wall tees can be less than those for a conventional structure of comparable height. In addition, base tees can be precast, which can reduce the requirement for field concrete for the precast wall assembly, which can effectively simulate a conventional cantilever retaining wall assembly.
Sdb's according to the present invention can be used to structurally connect the base tees to the wall tees. The sdb's can provide a competent structural connection sufficient to maintain wall stability and/or eliminate the need for corrosion-protection at the connection between the horizontal tee base and vertical wall tee. In other embodiments, other types of high tensile strength tendons can be used. Such high tensile strength tendons typically include adequate corrosion protection. High strength post tensioning bars can be used, but their use typically requires field grouting at the tendon connections.

In embodiments, where precast base tees are used, the tendon connections optionally can be visible prior to installing wall fill, and consistent quality control is possible at the grouting locations. Additionally, partial post tensioning of the wall tees to the base tees can be completed prior to placing wall fill. The use of both of these features with the precast tee cantilever wall according to the present invention can eliminate the need for corrosion protection, whether sdb's or post tensioned tendons are used to attach the tee members.

In an exemplary embodiment, for a typical wall site, following the wall footprint excavation, a level (or on grade), compacted base is prepared under the proposed wall footprint. Subsequently, the base tees can be placed at the wall alignment with the tee stems protruding upwards. The flat flange or deck portion of the base tee can be supported by the level fill. The wall face tees are then positioned over the base tees with the use of the appropriate lifting equipment. The stems of the wall tees are oriented towards the wall fill, and the flange or deck of the face tees are exposed to view. Additionally, the face tees can be fabricated with a face blockout at the bottom of the face tees that closely corresponds to the cross section of the base tee stems. The use of the stem blockout allows the face of the wall tee to project down to the back face of the base tees. This configuration can provide additional bearing area, if needed for taller wall applications. For typical wall heights, the projection of the face of the wall tees will typically not be required, and the face of the wall tees can be at the face of the top of the base tee stems.

At the plan location of the face tees on the base tee stems, a mating recess can be provided in the base stems, corresponding to the dimensions of the face tee stems. At the rear of the base stem, a void can be cast into the base stem to facilitate attachment of the wall tee to the base tee. As the wall tee is lowered onto the base tee, sdb's cast into the wall stems that extend (or protrude) out of the wall stems are inserted into the mating void that is cast into the base stems.

Although base tees placed on field graded surface can be at the proper orientation, it may be necessary to install shims at the horizontal mating surface of the base tee stem, so that the wall tee will be positioned in an essentially vertical orientation. The ability to shim the contact bearing interface of the wall and base stem over the relatively small area bearing surface allows orientation of the large wall panel. Therefore, exact field grade is not required, but can fall within reasonable tolerances.

Field grouting between the base of the wall tee stems and the top of the base tee stems can provide a competent, complete bearing surface to compensate for shimming heights needed to position the wall tee at the correct orientation. Following the insertion of the sdb's into the base stems and grouting between the base and wall tees, the void in the base stem around the protruding sdb's can be grouted or other wise have suitable bonding agent material (e.g., such as epoxy or the like) injected into the base stem void to encapsulate the sdb and effectively structurally bond the sdb between the wall and base members.

In certain embodiments where post tensioning tendons or high strength thread bars are utilized to attach the tees, the tendons or bars are typically inserted through a duct cast into the wall stem into a corresponding duct cast into the base stem. Following insertion of the tendon or bar through the wall tee stems, the tendons or bars are inserted into the appropriate connecting hardware, per the tendon or bar manufacturer. Nuts can be threaded onto the thread bar ends at the top of the wall stems to secure the wall tees in a vertical position prior to applying post tensioning forces to the bars.

If tendons, such as strand, are used to attach the tees, strand chucks or equivalent connectors can be used to make the connection between the wall and base tees. Optionally, by using a threaded or chuck connector at the top of the wall panels, the wall tees can be free standing and the need for temporary erection bracing can be eliminated.

Any of the aforementioned attachment methods typically form a bond between the base and wall tees sufficient to hold the face tees generally in a vertical position. Following the stable positioning of the face tee, the assembly is grouted at the appropriate time per the site-specific wall design at the base tee and face tee interfaces. Each wall tee component can have one or more tee protrusions, as needed, for efficient wall assembly or as is economically desirable for specific projects. The resultant base and wall tee assembly can simulate a conventional cast in place cantilever retaining wall, at a lower cost with a faster placement time without concerns for corrosion protection at the structural connection between the wall components.

Figure 12 depicts an exemplary double tee precast base cantilever wall system assembly 300 in the field assembly process. In the partial isometric view of the assembly 300, the precast base tees 202 are shown placed on a leveling course 204. The base tees 202 can be placed on the leveling course 204 in front of the face of excavation 206. The precast wall panels 208 can attached to the base tee 202 and positioned prior to attachment. The right portion of the isometric view shows a wall panel 208 attached to the base tee 202. On the left portion of the isometric view, a wall panel 208 is shown as it is lowered into place onto the base tee 202. The exposed portion of the stem sdb 210 is shown extending down towards the base stem 212 of the base tee 202.

As the wall panel 208 is placed onto and over the base tee 202, the protruding stem sdb 210 will penetrate into the stem void 214 in the base stem 212. Referring to the left side of the isometric shown in Figure 12, following placement of the wall panel on the base tee 202, the wall panel 208 is attached and interlocked by the shear key 216 and the stem sdb 210. The contact width 218 of the shear key 216 is typically equal to or slightly greater than the wall stem width 220. The wall panel 208 can be further restrained from any lateral motion by the interlocking effect of the face stem blockout 222, which conforms to or slightly exceeds the outer dimensions of the base tee stem 212.

Following the placement of the wall tee 208, the voids between the contact areas of the wall tee 208 and the base tee 202 at the shear key 216 are typically shimmed and grouted, as necessary. Optionally, the volume between the stem sdb 210 and the base stem void 214 can be grouted. If the stem void 214 is formed by a grout sleeve, the grouting is typically performed according to the manufacturer's specifications. If a generic grout sleeve serves as the stem void 214, then a similar process can be followed, per specific design parameters. Adequate grout or other bonding material injected into the stem void 214 can result in a bond that can ensure that the tension capacity of the stem sdb can be attained at the connection.

The width of the base tee 224 can be slightly less than the width of the wall tee 226. Either width can vary, as desired, due to wall alignment or curves without affecting the operation according to the present invention. The height of the base stem 228 and the thickness of the base flange 230 can be dependent on the moment induced on the base tee 202 by the wall loads placed on the wall tee 208. The thickness of the base flange 230 can also vary or taper from one side of the base tee 202 so that the slope or taper of the base tee 202 matches the base grade of any wall application. By providing a base tee 202 with a variable width 230, wall excavation can be more efficient at a constant grade, rather than excavating steps into the in situ material to approximate the base of wall elevation changes. Because the panel stem 213 is attached at the top of the base stem roughly corresponding to the height of the base stem 228 above the top of the leveling pad 204, the overall height of the wall tee 208 can be effectively reduced compared to that of a conventional cantilever wall for the same application. The decrease in the moment arm for the wall loads compared to length of the moment arm of a comparable conventional cantilever wall can roughly correspond to the height of the base stem 228.

The width of the base stem 228 can be, for example, between about three to about five feet (or more or less). The effective reduction in the

moment induced on the wall can be significantly reduced for the tee assembly compared to a comparable height cantilever wall due to the elevation of the wall panel connection made available with the use of the tee base 202. The shape of the base tee 208 can provide a substantially greater moment resistance with significantly less material than would be the case for a rectangular section cast in place base.

Figure 506 shows a tee wall panel 203 connected to a base tee 212 in a rear and vertical section view. The section line 366 on the rear View "a." shows the location of the vertical section. The section View "b." shows the base tee stem 212 at a deviation grade angle 368 orientation. The face deviation shows the potential tee wall panel orientation 370 due to the potential effect of the deviation grade angle 368. The grout volume 372 shown between the tee wall panel 208 and the base tee 212 over the contact area 374 corrects the face deviation 370, even though the contact width 374 is typically extremely small compared to the height of the tee wall panel 376.

Three vertical cross sectional views of a typical tee wall panel 208 and base tee 312 assembly are shown on Figure 508. The sections are cut through and parallel to the long dimension of the wall panel stem 213 as shown in the preceding Figure 506.

View "a." shows a threaded end extension sdb 40 utilized to connect the tee wall panel 208 to the base tee 212. The thread extension sdb 40 is secured to the base tee 212 at the base plate/nut assembly 378 within the base tee 212. The top tensioning nut 380 at the upper portion of the tee wall panel stem 213 is shown threaded onto the threaded end extension sdb61. Grout 382 injected in the injection tube 384 cast in the base tee stem 212 encapsulates the threaded end extension sdb 61.

View b. shows cable steel strand 386 utilized to connect the tee wall panel 208 to the base tee 212. The cable steel strand 386 is secured to the base tee 212 at the strand plate 379 within the base tee stem 212. The cable steel strand 386 at the upper portion of the tee wall panel

stem 213 is shown inserted into cable steel strand 386. Grout 382 injected in the injection tube 384 cast in the base tee stem 212 encapsulates the cable steel strand 386.

View c. shows steel threadbar 390 utilized to connect the tee wall panel 208 to the base tee 212. The steel threadbar 390 is secured to the base tee 212 at the base plate/nut assembly 378 within the base tee stem 212. The top tensioning nut 380 at the upper portion of the tee wall panel stem 213 is shown threaded onto the steel threadbar 390. Grout 382 injected in the injection tube 384 cast in the base tee stem 212 encapsulates the steel threadbar 390.

In another aspect of the present invention, sdb's placed in slots cut into the embankment can be used to anchor face tees to the embankment, such as for wall applications where a desired wall is located at the base of an existing sloping embankment. The sdb's can be used as tensionable members between wall tees and anchor components. Alternatively, aluminum alloy, steel alloy or other types of material commonly used as a tensionable material can be used. Typically, adequate corrosion protection is included for the tensionable member, as necessary.

The wall tees are typically placed on finite centers, although in other embodiments, the wall tees can be placed edge to edge. The horizontal distance between the tees can allow for the slots to be cut into the existing embankment so that the in situ material in the slope between the slots will remain stable. The slot or trench cut into the existing embankment can provide an anchoring void, so that when sdb's are secured to the face tees, the amount of excavation that would be required for a conventional cantilever or MSE wall is reduced.

For a typical tee slot cut wall construction, the base tees can be placed on level fill at centers corresponding to the distance between the wall panels. The face tees are then placed over and onto the base tees in a similar manner to that described previously. The face tees

can alternatively be placed on cast-in-place pads or have bases attached to the wall tees prior to placing in front of the slots. If tee base are used as a wall panel base, after the face tees and base tees are attached to form a structural unit, the face tees can be further secured to the embankment via horizontally disposed sdb's attached to the wall face stems and to deadmen or comparable anchors placed in the slots excavated out of the existing slope.

To form a complete wall face, additional panels can be placed between the flanges of the face tees between adjacent wall tees. The panels can be subsequently backfilled along with the face tees. Prior to placing significant fill behind the wall panels, the deadmen can be secured into the slots with compacted fill, a concrete encapsulation around the deadmen, or similar methods.

Referring to Figure 13, an isometric view of a tee wall panel 208 is shown in the tee/panel slot cut assembly 301. The tee wall panel 208 is held in a vertical position by sdb tie rod assemblies 240. For this type of wall application, the height of the wall can exceed the capacity of the stem sdb 210 (not shown) and additional horizontal restraint can be used, as necessary. To achieve vertical stability, the sdb tie rod assemblies 240 can be attached to the wall stems 213 situated in a substantially horizontal plane and also attached to deadmen 242. The deadmen 242 can be placed in a trench 246 cut into the face of excavation 244 behind the wall assembly 301. The trench width 245 and trench depth 248 provide a trench 246 cut into the existing embankment 250 that is typically of sufficient size for the placement of deadmen 242.

The deadmen 242, when encapsulated with fill concrete, concrete slurry, or other suitable material, can effectively secure the wall panels 208 in a vertical position due to the tensile capacity of the sdb tie rod assemblies 240. To provide anchorage for deadmen 242, the wall panel 208 and the tee bases 202 can be displaced horizontally a sufficient distance 252 from each other, so that the trenches 246 can be excavated

into the existing embankment 250. In certain embodiments, this tee spacing 252 can be slightly less than the width of the wall panel 254.

The wall panel 254 is supported by tee flange 256. As the wall assembly 301 is completed, wall panels 254 can be installed, as required, to equal an elevation equal to the tee panel 208 heights. A typical sdb tie rod assembly 240 connected to a wall stem 213 is shown in Figure 520. View "a" in Figure 520 shows a top view of adjacent tee wall panels 208 supporting a horizontal wall panel 254. The sdb tie rod assemblies 240 are shown inserted into the stems 213 of the tee panels 208.

View "b" in Figure 510 is a partial horizontal section through the tee wall panel 208 at the elevation of the sdb tie rod assembly 240. The horizontal wall panel 254 is shown bearing against the flange extension 256 of the tee wall panel 208. The threaded extension tie rod 61 (which is described in PCT/US01/05733 and in U.S. Provisional Patent Application Number 60/184,049, the disclosures of which are incorporated by reference herein) can be inserted through the stem circular void 258 in the stem 213 of the tee wall panel 208. The location of the stem circular void 258 can be anywhere within the tee wall panel stem 213, per specific structural panel design, without affecting the operation of the embodiment according to the present invention.

The face nut 260 can be threaded onto the end of the threaded extension tie rod connector 61. Face nut 260 bears on the plate 262, which transfers the tensile load of the threaded extension tie rod connector 61 to the flange 256 of the tee wall panel 208. Following the placement of the face nut 260, the nut access void 264 cast into the face of the tee wall panel 208 is typically filled with a cement grout (not shown). The connection of the tie rod assembly 240 to the deadman 242 can be completed in a similar manner to that shown for the sdb tie rod assembly 240 connection to the wall panel stem 213, or with any number of connection methods known to the skilled artisan. The connection of the tie rod assembly 240 to the tee wall panel stem 213 can also be done

with other configurations or with grout sleeves (not shown) without affecting the operation of the present invention.

In a related aspect, vertical concrete wall flood control channels are currently constructed with cast-in-place concrete and are usually required to have a smooth face so that the channel sides do not restrict flow in the channel. In addition the bottom portion or "invert" of the channel section is typically a poured-in-place concrete flat slab that is continuous for the reach or length of the channel. This structural application is another configuration that has application for the vertical free standing precast tee wall system.

For walls of this type, a typical cast-in-place design will show a long extension of the wall foundation in front of the face of the wall so that the typical limited right of way behind the wall face will not be encroached either during or following wall construction. To utilize the free standing precast tee wall system for the vertical wall channel wall applications, since the width of the majority of these channel is narrow, the base tee unit is manufactured to roughly correspond to the overall width of the channel. This unique feature of the system allows for one base tee section to be used for a foundation component for opposing wall panels (two panels) for each side of a parallel alignment vertical wall channel.

Additionally, the channel bottom that is exposed to flood flow, which is cast over the tee base, is not structural concrete, which can be the case for typical cast in place channels. When the free-standing tee system is used for vertical wall channel applications, the wall tees can be attached to the foundation tee, as has been previously described. Another option for some wall sites is to pre-assemble a base tee with two opposing wall panels and deliver the assembly to the site for installation as a unit. By providing pre-assembled units field construction time can be reduced since three wall components are placed with each crane placement compared to three components that would otherwise be placed.

Since channels typically require flow there will be a slope over the reach of most channels. One method to maintain a vertical orientation of the tee base extension stems, so that they will properly mate with the opposing wall tees, is to manufacture the base extension tee with a sloping base. By casting the slope of the base bottom to correspond to the slope of the channel the orientation of the base stems will be perpendicular. With this base configuration the mating surfaces of the wall tees will match the horizontal bearing surface of the base stems.

For high channel wall applications, where pre-assembled channels section are used, the pre-assembled portion of the channel can be produced to the maximum height wall that is feasible for transport to that site. Following delivery and placement of the pre-assembled units, the top panel of the channel is typically placed on top of the vertical wall tee panels. The maximum elevation of the top panels added to the existing tee panels on the pre-assembled units generally correspond to the design height of the vertical wall channel. The connection of the top panel to the lower base panel can be completed in a similar manner to the connections that have been previously described for the free-standing precast tee system. The unique feature of the connection of the top panel to the base wall panel is that the tension bar used for the attachment of the top panel to the base panel is inserted through the base wall tee stem and the top panel. The tension bar is anchored to the base tee stems in a comparable manner to what has been previously described and is also grouted in a similar manner. By passing the tension bar through both wall tees in the pre-assembled unit, the resultant taller wall tees act structurally as a single wall tee built to the overall wall height of the vertical wall channel.

In Figure 510, an isometric view of a tee channel assembly 392 being assembled. A tee wall panel 208 is shown being lowered onto an extended base tee 394. Additionally two opposing and parallel tee wall panels 208 are shown connected to an extended base tee 394. The tee wall panel 208 shown prior to attachment to the extended base tee 394 is connected

to the extended base tee 394 with the use of either cast in protruding sdb's 210, threaded extension sdb's 40, steel threadbars 390, or steel cable strand 386, as has been previously described in the prior embodiment descriptions. The wall panels 208 can either be connected to the extended base tee 394 in the field following placement of the extended base tees 394, or the tee wall panels 208 can be attached to the extended base tee 394 prior to delivery to the site. For sloping grades, the extended base tee 394 can be manufactured with a tapered base flange 396 (not shown) with a tapered height 231 greater than flat base flange 230 so that the wall panels 208 will be vertical since the tapered base flange 396 is equal to the slope of the grade of the base grade. The tapered base flange 396 can be used with this or any of the previously described tee systems without affecting the operation of the present invention.

Figure 512 depicts a vertical section through a tee channel assembly 392 at the vicinity of the tee wall panel 208 and extended tee base 394 attachment location. View a. shows a tee wall panel 208 with a cast in stem sdb 210 utilized to attach the tee wall panel 208 to the extended tee base 394. The cast in stem sdb extension 214 is shown encapsulated in grout 382 in the sdb stem void 214. Although not shown in this view the use of either threaded end extension sdb's 40, steel threadbar 390 or steel cable strand 386 can equally be used for this connection.

View b. in Figure 512 shows an extension tee wall panel 400 placed on the upper portion of the tee wall panel 208. Either a threaded extension sdb 40, steel thread bar 39 or steel cable strand 386 is shown connecting the extension tee wall panel 400 to extended base tee 394. The permanent connection of the extension tee wall panel 400 is completed in a similar manner to any of the other previously stated tensionable bar types that has been previously described for the other tee embodiments.

The use of double tee shaped sections supporting reverse batter flat

trapezoidal panels is described in U.S. Patent No. 5,468,098 issued November 21 1995 to John Babcock. For that system, the wall face can be landscaped due to the exposed inclined soil layers between subsequent tiers. The structural elements described in that patent require that the tee shaped support panels be anchored to wall backfill with tie rods secured to deadman. For this embodiment of the present invention, conventional deadmen are not required. Also the tee shaped support members are typically formed from standard double tee sections. Additionally the wall face batter and the reverse batter of the face panels are variable depending on the orientation angle of the base tee. This angle can be varied to conform to site requirements with minor form modifications.

For this embodiment, as with the other previously described MSE walls, the use of either sdb's or a combination of sdb's and geosynthetic soil tensile inclusion members are effective to form the MSE wall. Sdb's are utilized to secure the reverse batter wall facing wall and are in direct contact with and encapsulated in fill.

Referring to Figure 502, a partial elevation of a variable incline tee support panel retaining wall system 332 is shown. Trapezoidal face panels 334 are shown spanning between and supported by the face flange extension 326 of adjacent variable incline tee support panels 336.

Figure 504 shows a typical vertical section through an in-place assembly of variable incline tee support panels 336 and trapezoidal face panels 334 as well as rear and side views of a typical incline tee support panel 336.

View a. shows a base variable incline tee support panel 336 placed on an isolated foundation 338. The wall face incline angle 340 and the variable base angle 342 are shown. The remaining upper variable incline tee support panels 346 bear on the stem notch 348 of each subsequent lower variable incline tee support panels 346.

Void end sdb's 32 are shown held by stem pins 350. Void end sdb's 32 can either be straight or U-shaped or used in combination. In either case, the void end sdb's 32 are imbedded within an adjacent MSE wall 352 utilizing geosynthetic soil reinforcement 354. The void end sdb's 32 stabilize the variable incline tee support panels 346 & 336 and trapezoidal face panels 334, but are not subject to significant earth loading that is resolved by the adjacent MSE wall 352.

View b. in Figure 504 shows a rear and side view of a typical variable incline tee support panel 346. The rear stem notch 343 and stem sleeves 356 are shown in the side view. The orthogonal sides 358 forming the rear stem notch 348 correspond to the shape of the upper variable incline tee support panel 346 at the face of the variable incline tee support panel 360. The stem sleeves 356 are depicted by the inclined dotted lines on the side view. The void end sdb's 32 are inserted into the stem sleeves 356 prior to using the stem pins 350 inserted into the void end sdb's 32 to attach the void end sdb's 32 to the variable incline tee support panel 336 & 346. The rear elevation view of the variable incline tee support panel 346 shows the flange void 362 in the face flange extension 326 for the flange pin 364 used to maintain the position of the trapezoidal face panels 334. Other types of sdb connectors or connection locations to the sdb's 32 to the variable incline tee support panel 336 are equally acceptable and their use is also in conformance with the present invention.

Another wall type that can utilize a structural combination precast of tee wall panels and precast tee bases is the Stresswall precast counterfort wall, as described in U.S. Patent No. 4,668,129 (the disclosure of which is incorporated by reference herein). For this wall system the "L" shaped counterforts are currently typically precast monolithically. Due to height limitations of trucking transport, the counterforts are limited in height to a maximum of approximately 10 feet. This is substantially less height than would be the case for the previously described free standing precast tee wall/base system that can

be used for walls over 40 feet in height, due to the field assembly of the precast tee components.

Precast counterforts can be pre-assembled from precast tee sections. To utilize precast tees, the tension bars connecting the tees are oriented in a horizontal position. For example, precast components can be assembled as disclosed in the Benson et al US Patent No. Benson et al U.S. Patent No. 4,572,711, issued on Feb. 19, 1986 by using vertical high strength steel bars to connect vertical wall panel support members to precast or cast-in-place bases. In addition, extremely deep section (tall stem) double tees can be used to pre-assemble precast tie back or counterfort components for that system. Since the average wall tier height for the precast counterfort system is the 8 foot range, the resultant earth load for in place wall components for that system can be applied to the vertical portion of the tie back or counterfort at approximately one third up from the bottom or under three feet up from the base. Since large tee stems can approach 5 feet in depth, the use of horizontal tension bars placed in the top portion of the base stems can roughly correspond to the location of the horizontal earth load imposed on the counterfort by the retained wall face. Typically little, if any, moment is induced on the connection between the wall and base tee at the attachment point. Conversely, the Benson et al U.S. Patent No. Benson et al U.S. Patent No. 4,572,711, issued on Feb. 19, 1986 describes the connection location and vertical orientation of the connecting bars in opposition to the outward bending moment effect of the retained fill on the wall panels or face of the counterfort or tie back unit. By using deep section tees for the counterfort bases, the resisting tension member can be oriented linearly with the wall load imposed on a corresponding precast wall tee unit.

A similar connection, previously described for the free standing vertical face panel and base tee assembly, can be utilized for the precast tee/base counterfort assembly for the Stresswall counterfort system (U.S. Patent No. 4,668,129 issued May 26, 1987) the disclosure of

which is incorporated by reference herein. The major difference between the free standing tee assembly connection and the connection used for the precast counterfort tee assembly is the 90° difference of the orientation of the tension bar used to connect the wall tee and base tee for the counterfort tee. Synthetic deformed bars, threaded extension sdb's, high strength steel thread bars or steel cable strand can be used as the tensionable members to structurally connect the precast tee base to the precast tee wall face. This alternative use of tee assemblies to form the counterfort units can also provides more wall square footage for the tee assembly than is the case for the precast counterfort in current use. Also, by alternating the flat panel locations between the tee face and back of stem in an alternating pattern a wall face can be achieved with the tee assemblies very effectively for plantable wall applications. As with the other tee wall options previously described, production rates of the counterfort units can be increased.

Figure 514 shows two isometric views of a partial double tee counterfort 402 and single tee counterfort 403. View a. shows a single tee counterfort base 403. The face flange extension 326 supports a trapezoidal face panel 334. View b. shows a double tee counterfort 402. The double tee counterfort face support 407 is attached to the double tee counterfort base 409 with a trapezoidal face panel 334 in place against the face flange extension 326 of the double tee counterfort face support 407.

Figure 516 shows a partial plan view and vertical sectional view of a double tee counterfort 402. View a. shows a partial plan view of a double tee counterfort 402. The section line 366 shows the vertical section location shown in View b. in Figure 516. A horizontally disposed tension bar of either a threaded extension sdb's 40, steel thread bar 390, cast in sdb 210, or steel cable strand 386 can be utilized to structurally connect the double tee counterfort face support 407 to the double tee counterfort base 409. The previously described connection methods apply to the horizontally oriented tension bars 40, 390, 210,or 386.

Referring to Figure 19B, a perspective view of a double tee plantable counterfort wall 320 installation is depicted. The face of the double tee plantable counterfort wall 320 is a combination of generally horizontally disposed trapezoidal face panels 334 spanning between and supported by the double tee counterfort face supports 407. The trapezoidal face panel 334 alternatively bear on the face flange extension 326 and the rear stem face 328 of the double tee counterfort face support407. This arrangement of precast components is one of many acceptable methods of providing face landscaping 330 within a double tee plantable counterfort wall 320. This face geometry, as well as other configurations, that will allow for construction and or plantable areas of the double tee plantable counterfort wall 320 embodiment.

Figure 15 shows three optional vertical cross section views of the use of steel lap (hairpin) bars 93 or bar/plate combination 97 inserted in a drilled shaft in an insitu embankment for a typical soil nail application using sdb's for soil nails. SBD's 26 (without end connectors) are shown inserted in shaft 24. The hairpin bars 93 are shown with face resteel 32 through the bend 99 in the hairpin bar 93. Face resteel 32 is also shown placed under the plate 89 of the bar/plate combination. Grout 382 (not shown) encapsulates bars 26 and either bars 93 or bar/plate combination 97. Lap distance 169 assures proper bond of the face (not shown) to the bars 26.

The preceding examples are provided to illustrate the invention but not to limit its scope. Other variants of the invention will be readily apparent to one of ordinary skill in the art and are encompassed by the appended claims. All publications, patents, and patent applications cited herein are hereby incorporated by reference for all purposes.